JAVELIN FLIGHT SIMULATION-INTERACTIVE SOFTWARE FOR RESEARCH AND COACHES

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ABSTRACT

An interactive computer software package has been developed that simulates the flight of the men's new rules and ladies javelin's based on measured aerodynamic data. The program includes user directed inputs of the most important variables in javelin throwing with a comprehensive HELP section giving scientific and non-scientific descriptions of each variable as well as sets of realistic inputs to be used as a guide by the user. The user can assess the effects of small changes in each release variable in a way that is impossible to control in the field without having to put athletes through potentially hazardous experimentation.

The extensive software graphics reveal a real-time simulated javelin flight based on the user's input release data. The flight graphics include a window which zooms in on the javelin showing important flight information, and essential post flight information including simulated distance thrown and landing angle. Flight graphics are followed by options to dump information on black and white or colour printers, re-run the simulation in real time, input new release data, calculate the optimum release conditions and range possibilities for that particular thrower, or to choose an extensive graph plotting section. The graph plotting routines allow observation of flight characteristics (e.g. velocity variation during flight) relating to the simulation most recently performed. The colour coded graph section is an essential prerequisite for researcher, coach, teacher, student, athlete and manufacturer since it can be used to develop a mechanical and aerodynamic understanding of the event. Additional software material incorporated includes unconstrained optimisation algorithms and 3-dimensional contour mapping or isometric plotting using NAG library routines with the authors' extensive data libraries.

In conclusion, the package permits fine observations to be made comparing different javelins and small variations in athletic techniques using applied optimal control theory. The program has been used as an aid to coaches, researchers, teachers, students, manufacturers and, of course, the athlete and is primarily used as an aid in developing an understanding of this complex throwing event.

INTRODUCTION

A central feature in elite athletics is the problem of determining and eliminating errors in technique. This has two prerequisites, firstly there needs to be an optimum performance model to serve as a referencing system, and secondly variations from this model need to be assessed quantitatively and rectified. Obviously the latter cannot be attempted unless the former has been developed. In throwing events the ultimate performance parameter, range, is a function of the associated release conditions since the projectile's path cannot be affected by the thrower after release. During the airborne phase there are clearly defined gravitational and aerodynamic forces acting such that throwing can be considered as an initial (release) condition problem and the differential equations that describe the trajectory of any thrown implement are of the form:

$$\dot{\xi} = f(\xi)$$

where ξ at release (t=0s) is equal to $\xi(0)$ (*HUBBARD* and *RUST*, *1984*).

From this it can be shown that the complete trajectory, and therefore the range, of a thrown implement is already determined once the initial (release) condition $\xi(0)$ is chosen. The problem can be solved, and optimal release conditions found, if javelin flight can be accurately simulated. The state vector ξ comprises displacements, angles, velocities and angular velocities relating to the javelin at any specified time during flight. Similarly, $\xi(0)$ comprises displacements, angles, velocities and angular velocities at the instant of release, and since these are all determined by the thrower, there must be optimal sets of initial (release) conditions for each athlete which will produce a maximum range.

Computer simulations of javelin flight are now a common feature in javelin research (e.g. BEST, BARTLETT and SAWYER, 1989; HUBBARD and ALAWAYS, 1987), although the wide availability of simulation software is not yet apparent. It is the objective of this paper to present an interactive javelin flight simulation software package for use by researchers, manufacturers, teachers, coaches and, of course, the athlete.

NOTATION

The definitions that follow are based, whenever possible, on the notation and axes systems standards put forward by HOPKIN (1966) and the ROYAL AERONAUTICAL SOCIETY (1967). All definitions relate to or about the javelin centre of gravity (CG).

D Drag force; the resolved aerodynamic force acting parallel to the relative wind vector, V.

g Gravitational Acceleration.

I_y Moment of Inertia about the javelin's body axes y axis (pitch axis).

L Light Force; the resolved aerodynamic force acting perpendicular to the relative wind vector, V; in 2-dimensional simulation this lies in the earth axes XY plane.

m Javelin Mass.

M Pitching Moment; Moment tending to rotate the javelin about its body axes y axis (pitch axis) in the XZ plane of the javelin body axes.

q Pitch Rate; the angular velocity component in the XZ plane of the javelin body axes. In 2-dimensional simulation q = 0.

R Range; horizontal distance from the CG at release (t=0s, x(0) = 0m) to the point where the the javelin first touches the ground on landing.

t Time; t(0) represents the instant of release.

V Javelin CG Velocity with respect to air.

V_K Javelin CG Velocity with respect to earth.

V_n Nominal Velocity; the maximum release speed capability of a thrower at = 35^0 (athlete specific).

V_w In this paper V_w represents the air velocity relative to the normal earth horisontal x axis at a height of 1m; tailwind positive.

V_x The component of V_K along horizontal normal earth horizontal x axis.

V_z The component of V_K along the vertical normal earth vertical z axis.

x CG co-ordinate in the normal earth x direction (forwards positive).

z CG co-ordinate in the normal earth z direction (upwards positive, unlike HOPKIN, 1966).

α_K True aerodynamic Angle of Attack with respect to air; the angle between the javelin's x (long) axis and the projection of V on to the normal earth XZ plane.

α_K Angle of Attack with respect to earth; as α except V_K is projected instead of V (i.e. $\theta-\gamma$ in 2-dimensional simulation).

γ Angle of Climb; the direction angle of V_K relative to the horizontal plane of the normal earth axes; $\gamma(0)$ = Angle of Release.

θ Inclination Angle; the attitude angle between the javelin x (long) axis and the horizontal plane of the normal earth axes.

(0) as in q(0) denotes a parameter value at the instant of release, t(0).

Dot as in $\dot{q}$ denotes differentiation with respect to time.

Dash or prime as in q' denotes a perturbation.

Some of the more important variables for 2-dimensional motion are shown in Figure 1, where the above notation are conceptually simplified.

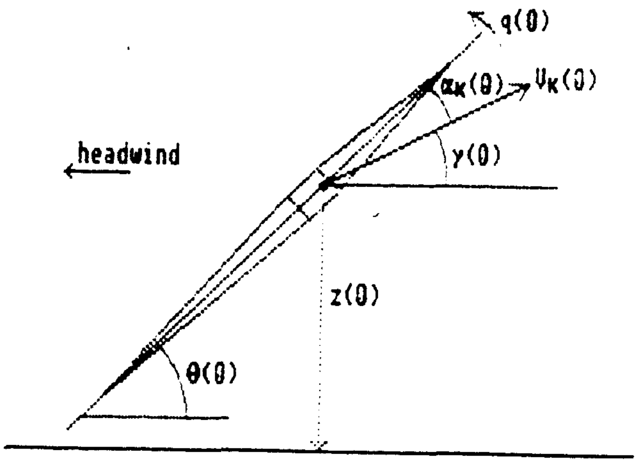

Figure 1: Some important release variables

FLIGHT SIMULATION

An important assumption in present flight simulation research is that all javelin activity in flight occurs in a single vertical plane (normal earth XZ plane), thus reducing the problem to two dimensions. This assumption is considered reasonable(BARTLETT and BEST, 1988; HUBBARD, 1984).

A 2-dimensional computer simulation of javelin flight essentially consists of two stages. Firstly, a complete set of aerodynamic force and moment data for the relevant range of angles of attack and air speeds encountered in javelin flight are required. The vertical plane aerodynamic model described by BEST and BARTLETT (1988, 1989) fulfils the 2-dimensional criteria involved. The second stage of the computer flight simulation involves a method for predicting javelin position's angles, velocities and angular velocities at any time during the javelin's flight. There are six differential equations of motion to be solved (three first order, x z θ and three second order, x z θ). Using earlier definitions, these six differential equations can be expressed as first order by resolving, viz;

$$x = V_x$$
$$z = V_z$$
$$\theta = q$$
$$x = V_x = -(L\sin\gamma + D\cos\gamma)/m$$
$$z = V_z = (L\cos\gamma - D\sin\gamma - mg)/m$$
$$\theta = q = M/I_y$$

and for the above to be solved, four further equations are required since $L,D,M = L,D,M(V,\alpha)$ and $\alpha = \alpha(\gamma, \theta, V_w)$;

$$\gamma = \tan^{-1}(V_z/V_x)$$

$$\alpha = \alpha_k + \sin^{-1}(-\sin\gamma * V_w/V)$$

$$V^2 = V_w^2 + V_k^2 + (2 * V_w * V_k * \cos\gamma)$$

$$V_k^2 = V_x^2 + V_z^2$$

The differential equations are solved numerically using the Runge-Kutta 4th order method (e.g. SCRATCH, 1986) with L,D and M recalculated during each of the four steps, and all equations solved simultaneously. Since $x(0) = 0m$, Range can be expressed viz;

$$R = R(V_k(0), \gamma(0), \alpha_k(0), q(0), z(0), V_w)$$

The above equation for Range reveals the user input requirements for javelin flight simulations software.

The final assumption relates to the fact that an athlete throws at a different release speed, $V_k(0)$, for each value of angle of release, $\gamma(0)$. The speed/angle relationship used by the authors was calculated by replotting the data of VIITASALO and KORJUS (1988) and fitting polynomials based on the principle of parsimony, such that:

$$V_k(0) = V_N - 0.02825 * (\gamma(0) - 35) - 0.00223 * (\gamma(0)^2 - 35^2)$$

SOFTWARE

The computer software presently runs on an Acorn Archimedes 300 and 400 series microcomputer and will soon be available on PC based systems. The chosen programming language is structured BASIC V since BASIC is the most popular and widely used programming language and the most suited to the wide range of users for whom the software is written.

The main program includes user directed interactive keyboard inputs based on the equation;

$$R = R(V_N, \gamma(0), \alpha_k(0), q(0), z(0), V_w)$$

with an added input allowing a choice of IAAF approved competition javelins including men's Apollo 100m new rules javelin and ladies 600g Apollo Aerodyne javelin. This section of the program features a comprehensive HELP section giving scientific and non-scientific descriptions of each variable as well as sets of realistic inputs to be used as a guide by the user. Graphics diagrams are used as an additional aid with, for example, the relevant variable (e.g. q(0)) from Figure 1 flashing when the respective parameter value is to be entered. If a parameter value is entered that is outside the usual range of values encountered in the javelin event the user is given a caution and the option to enter a new value for that variable. This is one example of the numerous debugging procedures designed to avoid a program crash. The most striking advantage of this section is that the user can assess the effects on range of small changes in each release variable separately in a way that is virtually impossible to control in the field, and indeed, assess small changes in athletic technique in an applied sense when used in conjunction with high speed cinematography (BEST, 1988).

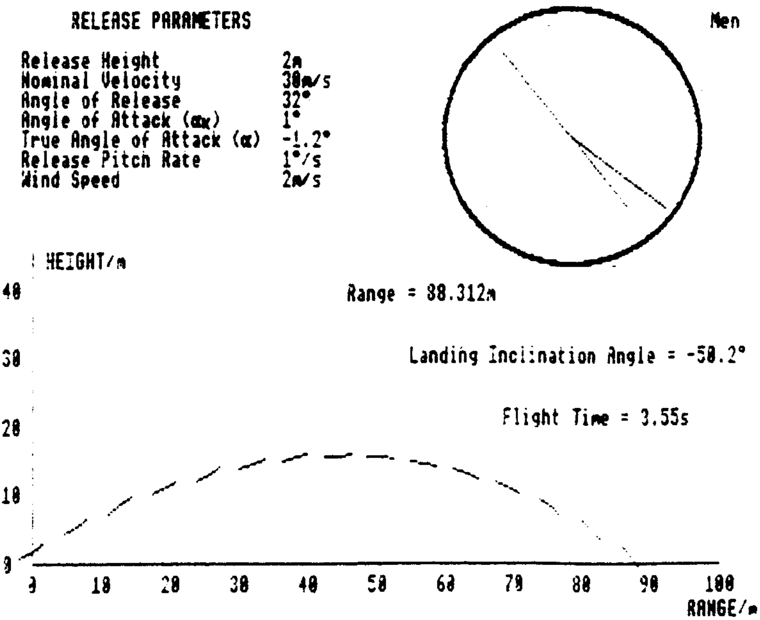

Figure 2: Post-flight javelin simulation graphics

Following the user input section, colour graphics reveal a real-time simulated javelin flight based on the user supplied release parameter data, culminating in information described in Figure 2. Flight graphics include a window zooming in on the javelin to show its inclination and the direction of V_k. Finally, flight graphics are followed by options to dump information into colour or black and white printers.

Since range can be accurately simulated and the release variables $\gamma(0)$, $\alpha_k(0)$ and $q(0)$ are optima variables (BEST, BARTLETT and SAWYER, 1989), there must be an optimal set of these variables for any given set of V_N, $z(0)$ and V_w, such that when differentiating with respect to Range (R);

$$q(0)' = \alpha_k(0)' = \gamma(0)' = 0$$

The optimisation algorithm chosen for this software is the DSC method of Davies, Swann and Campey (BOX,DAVIES and SWANN, 1969). This method, an extension of and superior to Rosenbrock's method, is an unconstrained linear, direct search optimisation algorithm (unconstrained because the simulation does not predict flat landings in either men's or ladies javelin throwing, the latter being a limitation of the research being looked at presently; BEST, 1988). DSC was chosen in preference to the more common and quicker Powell's method because Powell's method, while being most efficient in the region of the optimum where the function (R) can be well approximated by a quadratic, can prove inefficient for complex nonsymmetrical surfaces and when the starting point is a long way from the optimum. The latter is certainly a possibility since the initial guess or starting point is from the user input data. DSC overcomes these possible inefficiencies and is programmed within the software in order to encompass n-dimensional optimisation problems in Euclidean vector space, and continuously using ongoing information to redefine mutually orthonormal direction vectors via Gram-Schmidt orthonormalisation relationships (BIRKHOFF and MACLANE, 1966). This enables DSC to cope with the ridges and skews of more complex surfaces. Additional software programmed in ANSI Fortran 77 is also available allowing 3-dimensional contour mapping and isometric plotting using NAG library routines and the authors' extensive data libraries.

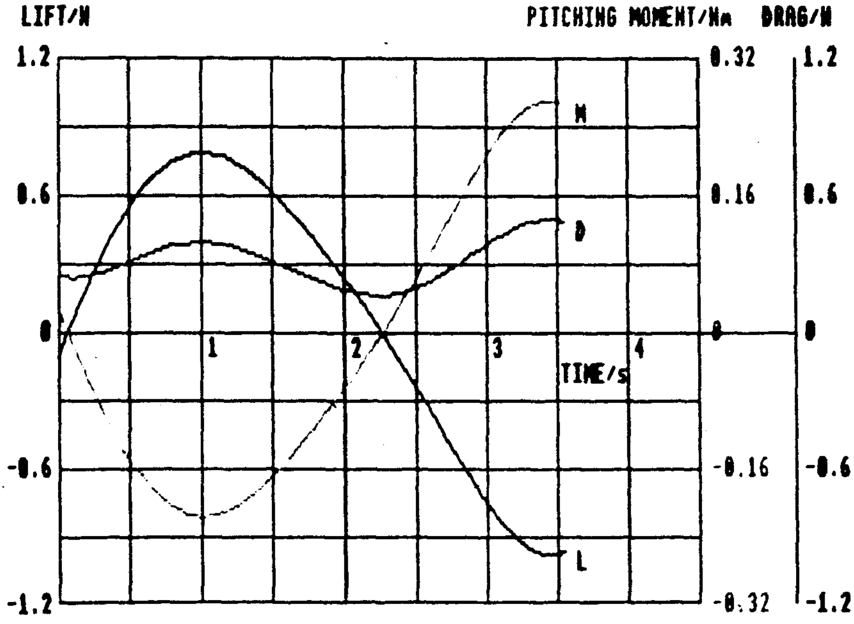

Figure 3: Lift, drag and pitching moment profile (Fig. 2 release data)

The optimisation routine is followed by a choise to re-run the original simulation in real time, input new release data or to choose an extensive graph plotting section. The latter allows observation of various flight characteristics using the authors' own 5-point, colour coded graph plotting routines. For example, Figure 3 shows the aerodynamic forces and moments acting during the flight described in Figure 2, while Figure 4 shows pitch rate variations during flight, emphasizing the now familiar constant negative (nose down) rotation of the men's new rules javelin. The graph section is an essential prerequisite for researcher, coach, teacher, student, athlete and manufacturer since it can be used to develop an understanding of this complex aerodynamic and mechanical throwing event.

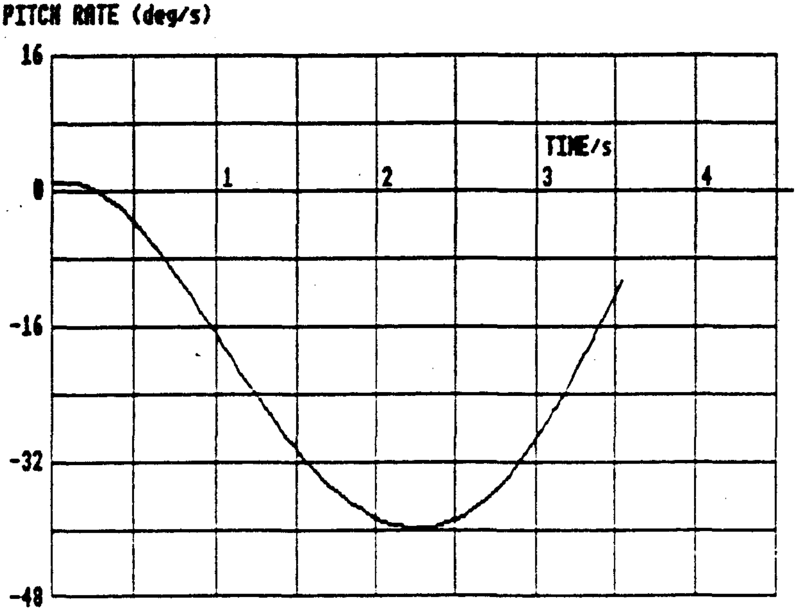

Figure 4: Pitch rate profile (Fig. 2 release data)

CONCLUSIONS

A javelin flight simulation software package has been developed as a research/learning tool for coaches, athletes, research scientists, manufacturers and university teaching of this complex athletic event.

The software includes real-time flight graphics, a comprehensive HELP section, optimisation of athlete specific release variables, measured aerodynamic data and graphical flight analysis section.

The main advantage of the program is that it can be used by the coach to assess on computer what is wrong with aspects of an athlete's technique without putting those athletes under potentially hazardous experimentation in the field.

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